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DOCUMENT-IDENTIFIER: US 3628394 A
TITLE: OPERATOR-MANIPULATIVE CONTROL APPARATUS

Brief Summary Text (7):
More specifically, three horizontally disposed leaf springs equiangularly distributed about the center post are connected to the upper and lower support rings by vertically directed coil springs so as to flex in response to up/down motion (heave) of the sphere and rotation thereof about orthogonal horizontal axes (pitch and roll) or any combination of such motions. Three sets of vertically disposed springs are also equiangularly distributed about the center post, each set consisting of one spring cantilevered vertically upward and another spring cantilevered vertically downward. The upwardly extending leaf springs are each coupled by horizontally directed coil springs to the upper support ring and the downwardly extending leaf springs are similarly connected to the lower support ring thereby enabling the vertically disposed leaf springs to flex in response to both rotation (yaw) of the shell about the longitudinal (vertical) axis of the center post and translation of the shell along orthogonal horizontal axes (surge and sway) or any combination of such rotation and translation. Strain gauges mounted on the leaf springs and connected in appropriate voltage divider or bridge circuit configurations provide electrical signals representative of the displacement and rotation of the shell in the six degrees of freedom. In particular, the gauges affixed to the vertically disposed leaf springs for sensing yaw, surge and sway are arranged in a manner to cancel any pitch and roll commands that are coupled thereto. As a consequence, the electrical signals provided by the strain gauges are directly representative of the operator applied forces and torques.

Detailed Description Text (5):
In operation of the device, motion of the sphere as described above will produce command signals for transmittal to the propulsion system of a remotely controlled vehicle. The command signals are obtained from strain gauges 40a and 40b mounted on the horizontal leaf springs, as by cementing thereto, and gauges 45a and 45a.sub.u mounted on leaf springs 30a and 30a.sub.u, respectively. Additional strain gauges are similarly mounted on the other leaf springs. In actuality, strain gauges are provided on both sides of each of the cantilevered leaf springs to produce the command signals as will be described hereinafter with reference to FIGS. 3a and 3b. Each strain gauge provides a signal having an amplitude essentially proportional to the extent of flexing of the spring on which it is mounted. In this regard it should be noted that the coil springs connecting the cantilevered leaf springs to the upper and lower support rings 23, 26 are preferably selected to provide a high degree of constraint along their lineal axis and comparatively low constraint transverse to said axis. The coil springs are thus able to resist expansion or contraction along their lineal dimension and therefore cause flexure of the related leaf springs in response to forces so directed. In the direction orthogonal to the lineal dimension, however, the coil springs readily flex in response to forces applied to the sphere and therefore do not couple such operator applied forces to the leaf springs. Thus, by this manner of construction in conjunction with the strain gauge arrangement as described in the following paragraph, the applied forces are not erroneously coupled into other command channels.

Detailed Description Text (10):
First, consider the control for forward-aft (surge), starboard-port (sway), and yaw

motion of the vehicle. These controls will be described with reference to FIGS. 5a, 5b and 5c which for convenience of illustration depict only the upwardly extending leaf springs. It will be understood, however, that the comments pertaining thereto apply as well to the downwardly extending springs. Referring to FIG. 5a, assume that an operator force is applied in a manner which tends to translate the spherical housing in the fore-aft direction, such force being represented by the vector F.sub.x oriented parallel to the plane of leaf spring 30c. This force is resolved into vector forces F.sub.a and F.sub.b directed normal to the planes of leaf springs 30a and 30b respectively, thereby producing signals of appropriate magnitude and polarity at the output terminals of the bridge circuits described hereinbefore. These output signals are utilized to produce proportionate forces f.sub.a and f.sub.b, respectively, from the horizontally directed propellors 54a and 54b in a manner to translate the vehicle in the same direction as the controller housing is translated by the operator. As previously explained with regard to the operation of the strain gauge circuits, an oppositely directed force applied by the operator will reverse the direction of the strain gauge output signals and cause the horizontal propellors to produce a thrust in the opposite direction from that described above. As shown in FIG. 5b, a force F.sub.y, orthogonal to the force F.sub.x, affects all three strain gauge outputs, the force F.sub.y being resolved into components F.sub.a, F.sub.b, and F.sub.c at leaf springs 30a, 30b and 30c, respectively, where F.sub.c is larger than F.sub.a and F.sub.b by one-half as determined by the angular orientation of the springs with respect to the applied force, and corresponding vehicle forces f.sub.a, f.sub.b, f.sub.c at thrusters 54a, 54b, 54c. In the case of yawing motion where the operator applies a torque to twist the housing about the support post, a clockwise torque Ycw as shown in FIG. 5c is resolved into forces F.sub.a, F.sub.b, and F.sub.c at the corresponding springs 30a, 30b and 30c resulting in similarly directed thrust forces f.sub.a, f.sub.b, f.sub.c at thrusters 54a, 54b, 54c which cause the vehicle to rotate about a vertical axis 60 extending through the center of the vehicle floatation ball 51 and cylindrical section 52.

Detailed Description Text (11):
The control for up-down (heave), pitch and roll motion is accomplished in a similar manner by means of electric signals coupled between the horizontally disposed of leaf springs of the controller and the vertically oriented propellors on the vehicle. It will be noted that the signal gain for these controls is half that provided for the three previously described controls since only two strain gauges are involved as compared to four in the bridge circuit arrangements of the vertically disposed leaf springs. In any event, additional gain can be realized if required simply by incorporating appropriate amplifying devices in the signal path between the controller and the vehicle propellors. In the case of a heave command for moving the vehicle downward an operator force F.sub.z (FIG. 5d) applied to the controller housing is sensed by the gauges on springs 20a, 20b and 20c as forces F.sub.a, F.sub.b, F.sub.c to produce equivalent downward directed forces f.sub.a, f.sub.b, f.sub.c at the vertically oriented propellors 53a, 53b and 53c. For a clockwise roll command Rcw, as shown in FIG. 5e, about a horizontal axis 44 parallel to the plane of leaf spring 30c the applied force is sensed by gauges on the springs 20a and 20b as upward and downward directed forces F.sub.a and F.sub.b respectively, which result in equivalent thrust vectors f.sub.a, f.sub.b at thrusters 53a, 53b causing the vehicle to roll about horizontal axis 44'. In a similar fashion a pitch force Pcw about horizontal axis 45', as indicated in FIG. 5f, will be sensed as a downward force F.sub.c at leaf spring 20c and as upward forces F.sub.a and F.sub.b at leaf springs 20a and 20b producing correspondingly directed thrust vectors f.sub.a, f.sub.b, f.sub.c, at vertically oriented vehicle propellors 53a, 53b, 53c causing the vehicle to pitch about the horizontal axis 45 orthogonal to the axis 44 of FIG. 5e.

Detailed Description Text (13):
As a further point of interest the affect of the pitch and roll commands upon the vertically oriented springs must be considered. As explained above, these springs are normally associated with yaw and horizontal translation control; but from a study of the drawings, it will be apparent that these springs will also flex in response to pitch and roll commands. Compensation for this undesirable cross-coupling is achieved by the unique arrangement of the strain gauges and will be explained for illustrative purposes with reference to a pitch command applied as described in connection with FIG. 5f. In response to such a command gauges 45a.sub. u and 45a' (FIG. 1a) are placed under tension while gauges 45a' .sub.u and 45a are compressed. As a consequence, the

voltages at output terminals 36 and 37 (FIG. 3b) remain unchanged. The same conditions prevail for the gauges mounted on leaf springs 30b , 30b.sub. u and 30c , 30c.sub. u so undesired coupling is avoided for both pitch and roll commands.

Detailed Description Text (14):
Finally, it can be seen by referring to FIG. 2 that motion of the control housing is limited for roll, pitch, surge, sway and heave commands by physical contact of the shell 13 with either the support post 10 or the mechanical stop members 17, 19. Yaw motion, on the other hand, is limited as shown in FIG. 1b by physical contact of the protrusions 22 with the sides of slots 21.